INTRODUCTION

by the National Aeronautics and Space Administration to investigate

science study areas (areas of particular scientific interest) on Mars. The

east Mangala Valles area merits detailed geologic study because it

contains several small channels whose ages can be determined relative to

geologic units that range in age from early (Noachian) to late (Amazonian)

periods of Martian history. Because the small channels are of three ages

and geomorphic types, their study increases our understanding of the

continuity of fluvial processes in the evolutionary history of Mars. For

these reasons, part of the area is a candidate site for a sample-return

The map was compiled on a Viking 1:500,000-scale photomosaic

base (U.S. Geological Survey, 1985). Some map units correspond or are

partly equivalent to units on smaller scale maps (Mutch and Morris, 1979;

Scott and Schaber, 1981; Scott and Tanaka, 1986) and the formal

terminology proposed by Scott and Tanaka (1986) was followed where

feasible. However, in many places interpretations and contacts have

been revised to reflect information visible on high-resolution Viking

images; geomorphologic details on these images were clarified by spatial

filtering (Condit and Chavez, 1979). The depths of channels, thicknesses

of geologic units, and heights of scarps prevalent in the area were

obtained in places by using photoclinometric methods of Davis and

Soderblom (1984). Geomorphology of channels and stratigraphic rela-

tions of geologic units observed on both computer-enhanced and

nonenhanced high-resolution images provide new information regarding

the geologic history and hydrologic activity of the east Mangala Valles

The relative ages of small channels and faults were established by

their stratigraphic relation to geologic units that are either overlapped or

transected by these features. Ages of the geologic units, in turn, were

determined by stratigraphic relations and crater counts (fig. 1). Cumula-

tive densities of craters whose diameters are greater than 1 km,

normalized to 106 km², are listed in the unit descriptions, except as noted

for the oldest unit, Noachian ridged plateau material. (The production-

GEOGRAPHIC SETTING

Valles, a north-trending channel system 850 km long and 150 km wide.

The system is thought to be a result of catastrophic flooding (Milton,

1973; Baker and Milton, 1974; Sharp and Malin, 1975). Mangala Valles

appear to originate at one of the east-trending faults of Memnonia Fossae

that lies 530 km south of the map area, at about lat 18.5° S., long 149°. The

small channels on Terra Sirenum, east of the Mangala branches, also

trend north; most, like Mangala, terminate at the scarp that separates the

STRATIGRAPHY OF PLAINS AND WALL MATERIALS

NOACHIAN SYSTEM

plateau material (unit NpIr) and remnants of highly degraded impact

craters (unit c₁). The ridged plateau unit has very rough, dissected, and

cratered surfaces. It is exposed both as outliers of extensive masses that

extend for hundreds of kilometers south of the map area and as narrow

bands along north-trending scarps. The material lacks diagnostic geo-

and origin. Noachian materials are locally mantled by younger plains

HESPERIAN SYSTEM

are covered by a mantle of moderately rough intercrater plains material

(unit Hpi). This unit is interpreted to be thin deposits of volcanic material

and volcaniclastic (reworked Noachian) material deposited by fluvial and

possibly eolian processes. The interpretation is based on the apparent

lack of c1-age impact ejecta, the presence of degraded channels

underlying the intercrater plains and older material (southwest of the

bombarded volcanic deposits (Scott and Carr, 1978). Some of the

ancient impact ejecta may have been blanketed by volcanic material or

eroded away; the degraded channels indicate that, in places, erosion was

by fluvial processes. Some of the degraded channels southwest of the

map area are locally overlain by Hesperian ridged plains material and cut

HESPERIAN AND AMAZONIAN SYSTEMS, UNDIVIDED

(unit AHpI) within topographic lows in the central and western parts of

the map area. Sparse, low, lobate scarps are contained within and bound

the unit, rising in broad steps to the south. The unit overlies terraces cut by Mangala Valles and can be traced southward to Memnonia Fossae.

Because the lobate scarps are a type of geomorphic indicator that

suggests basaltic volcanism (Greeley and Spudis, 1981; Scott and

Tanaka, 1982), the unit is interpreted to be composed of basaltic lavas.

They appear to have flowed north from vents associated with Memnonia

Fossae. Furthermore, a mafic (low silica) composition for Martian

igneous rocks is consistent with independent lines of evidence such as

Viking Lander data, remote-sensing data, and geophysical modeling

The old lobate plains unit is overlain to the east by member 3 of the

Tharsis Montes Formation (unit AHt₃), which consists of numerous

overlapping tongues of varied thickness and extent bounded by low,

lobate flow fronts. The flows are draped over the theater-headed channel Munda Vallis at lat 5.5° S., long 146.2° and over the highland-lowland

boundary scarp here and eastward. The unit also contains a leveed lava

channel that overlies the scarp at lat 5° S., long 145.7°; such channels

further suggest basaltic volcanism (Greeley and Spudis, 1981). The

stepped flow fronts rise southeast, toward Tharsis Montes. This plains

unit is interpreted to be basaltic lavas that are possibly associated with

intermediate stages of Tharsis volcanism. Overlapping flow lobes of

varied extent and thickness may imply multiple cooling units resulting

from volcanism more protracted, sporadic, and with a lower rate of

effusion than that of simple, uniform, lava-plain flows (Greeley and

Spudis, 1981). The unit was described by Scott and Tanaka (1986), but

the contacts have been revised on the basis of high-resolution data. The

unit is equivalent to Scott and Schaber's (1981) Arsia Mons flow unit 3

AMAZONIAN SYSTEM

zonis Planitia in the northern part of the map area. The unit contains

some low, lobate scarps and appears to be relatively smooth, displaying

local areas of fine sublinear ridges and depressions that may be pressure

ridges and cooling cracks. On the basis of its lobate scarps and fine

sublinear features, the material is interpreted to be another basaltic flow unit; the local absence of these features may be due to mantling by eolian

Young lobate plains material (Apl₂) occurs in a 450-km-long eastwest belt in Amazonis Planitia north of the highland-lowland boundary

scarp. At moderate resolution this material appears smooth, but at high

resolution it has a very rough texture of fine sublinear ridges and

depressions whose relief is as much as 10 m. Its contact with older

material is a continuous 30-m-high lobate and crenulate flow margin;

local, subparallel, concentric ridge-and-trough patterns are seen behind

the margin. Tongues of the unit extend into several of the small channels

that cut the highland-lowland boundary scarp. The unit is interpreted to

be the youngest basaltic lava deposit in the map area. Individual flows as

long as this one (450 km long) suggest extremely high eruption rates as

Smooth plains material (unit Aps) occurs locally on Terra Sirenum,

partly covering the floors of most large impact craters. On the basis of its

smooth surface and its occurrence in topographic depressions, the unit is

The two younger lobate plains units are overlain by the upper

member (unit Amu) of the Medusae Fossae Formation (Scott and

Tanaka, 1986); this unit forms a varied but relatively high albedo blanket

in the northern part of the map area. Its contact with older units is

traceable as an arc hundreds of kilometers long having serrated or thinly

feathered edges. The unit has no visible bedding and is nearly featureless,

with the exception of streamlined ridges of Amazonis Sulci, interpreted

by Ward (1979) to be yardangs, and intervening grooves along the south

margin. The unit may be 2 to 3 km thick (Scott and Tanaka, 1982); it is 1

km thick where it overrides and spills into a crater west of the map area at

lat 6.5° S., long 156.1°. Although the origin of this poorly indurated

material is not yet fully understood, Scott and Tanaka (1982) interpreted

it to be an ignimbrite on the basis of its morphologic similarities to

terrestrial ignimbrite material. Outside the map area (for example, at

about lat 1° S., long 147°), the unit appears to be associated with

collapsed calderas that occur as elongate depressions within its central

material deposited when the area may have been close to a previous

polar position (Schultz, 1985; Schultz and Lutz, 1988) and equivalent in

age to the oldest lava flows from Tharsis Montes (Hesperian; Scott and

CHANNELS AND HYDROLOGIC HISTORY

channels are ancient (Sharp and Malin, 1975; Pieri, 1980; Carr and Clow, 1981; Baker and Partridge, 1986), and Masursky and others (1977) have

suggested that the large outwash channels range widely in age. Baker and

Partridge (1986) noted that at least two episodes of small-scale channeling

occurred during Noachian time in the equatorial region of Mars. Mapping

in the east Mangala Valles area indicates that small channels formed in

three separate channeling events ranging from Late Hesperian to Early

Amazonian time. Materials of these channel floors are mapped as those

of (1) the Mangala Valles branches (unit Hchm), (2) the theater-headed

channels (unit AHcht), and (3) the ribbon channels (unit Achr). The small

channels are of three morphologically different types that can be

classified by their width-to-depth ratios, but the entire Mangala Valles

channel (whose branches separate and rejoin) cannot be so classified.

The recurrent nature of channeling suggests intermittent hydrologic

activity on Mars, and the changing style of channel morphology may

further imply that processes of channel formation were dominant in or

CHANNEL TYPE 1: MANGALA VALLES BRANCHES

side branches of the main Mangala Valles channel. They cut and are

therefore younger than intercrater plains material, but they are older

than old lobate plains material (unit AHpI) because terraces cut by

Mangala Valles and these two branches are overlain by the volcanic unit.

Both side channels are broad and shallow; Asopus is about 80 km long

and 6 km wide, and Padus is about 60 km long and 3 km wide. Their

depths are about 200 and 300 m, respectively; by contrast, depth of the

mouth of the main Mangala channel is 700 m. The average width-to-depth

ratio of the two side channels is 22. Their floors are relatively flat,

containing small, streamlined, elliptical mounds (interpreted as deposi-

tional fluvial bars). The presence of these probable fluvial bedforms in

both channels and the shallow depths of the branches compared with

that of the mouth of the main Mangala channel imply that the present

morphology of Asopus and Padus formed in an aggrading system.

However, if these channels formed during the initial catastrophic flooding

that produced the main Mangala channel, the deeper Mangala channel

may have been carved by waning flood stages, additional flooding, and

later sapping without involving Asopus or Padus. The release of large-

scale floods that produced Mangala Valles may have been triggered by

CHANNEL TYPE 2: THEATER-HEADED CHANNELS

lack tributaries; individual channels have nearly constant widths. The

channels are relatively short and their overall morphologic appearance is

stubby. They contain smooth floor deposits (unit AHcht). These

channels cut both intercrater plains and old lobate plains materials, but

they formed before deposition of member 3 of the Tharsis Montes

Formation, which covers some channel heads (fig. 2A). The channels

average width-to-depth ratio is 11. These stubby channels may be

structurally controlled because, although they are outside the Mangala

channel system, they too exhibit pervasive northward trends. The

channels are interpreted to have formed by ground-water sapping

because their morphologic characteristics are common to terrestrial

canyons formed by this process (Pieri, 1980; Laity, 1983; Laity and Malin,

Abus Valles, a theater-headed channel, and covers part of the ribbon

channel incised into its floor (fig. 2C). The average width-to-depth ratio of

the ribbon channels is 14. Interpretations as to origins of extremely small

features are tenuous; however, two of the channels display aspects that

may indicate a fluvial origin. One sinuous channel cuts a depositional lobe

at the mouth of the east channel of Isara Valles. It bifurcates downstream

range from 100 to 1,500 m in depth and from 1 to 3 km in width; the

In the map area are ten channels that originate at theater heads and

the development of Tharsis volcanism (Greeley and Spudis, 1981).

Asopus and Padus Valles, near the west edge of the map area, are

unique to specific periods in the Mangala Valles region.

Many investigators have theorized that most, if not all, small Martian

interpreted to be young eolian deposits.

well as low-viscosity lava (Walker, 1972; Greeley and Spudis, 1981).

Intermediate lobate plains material (unit ApI₁) occurs within Ama-

(whose Amazonian age was based on Mariner 9 data).

dust or erosion.

Tanaka, 1986).

Intercrater plains material is overlain by old lobate plains material

by Labou Vallis, a branch of Mangala Valles.

results (Greeley and Spudis, 1981).

pap area at lat 7° S., long 158.2°), and the assumption, based o planetwide geologic mapping, that Noachian material consists of heavily

Large parts of Terra Sirenum and small areas in Amazonis Planitia

morphic features such as flow fronts that are useful indicators of lithology

The oldest recognized geologic units in the map area are ridged

Terra Sirenum highland from the Amazonis Planitia lowland.

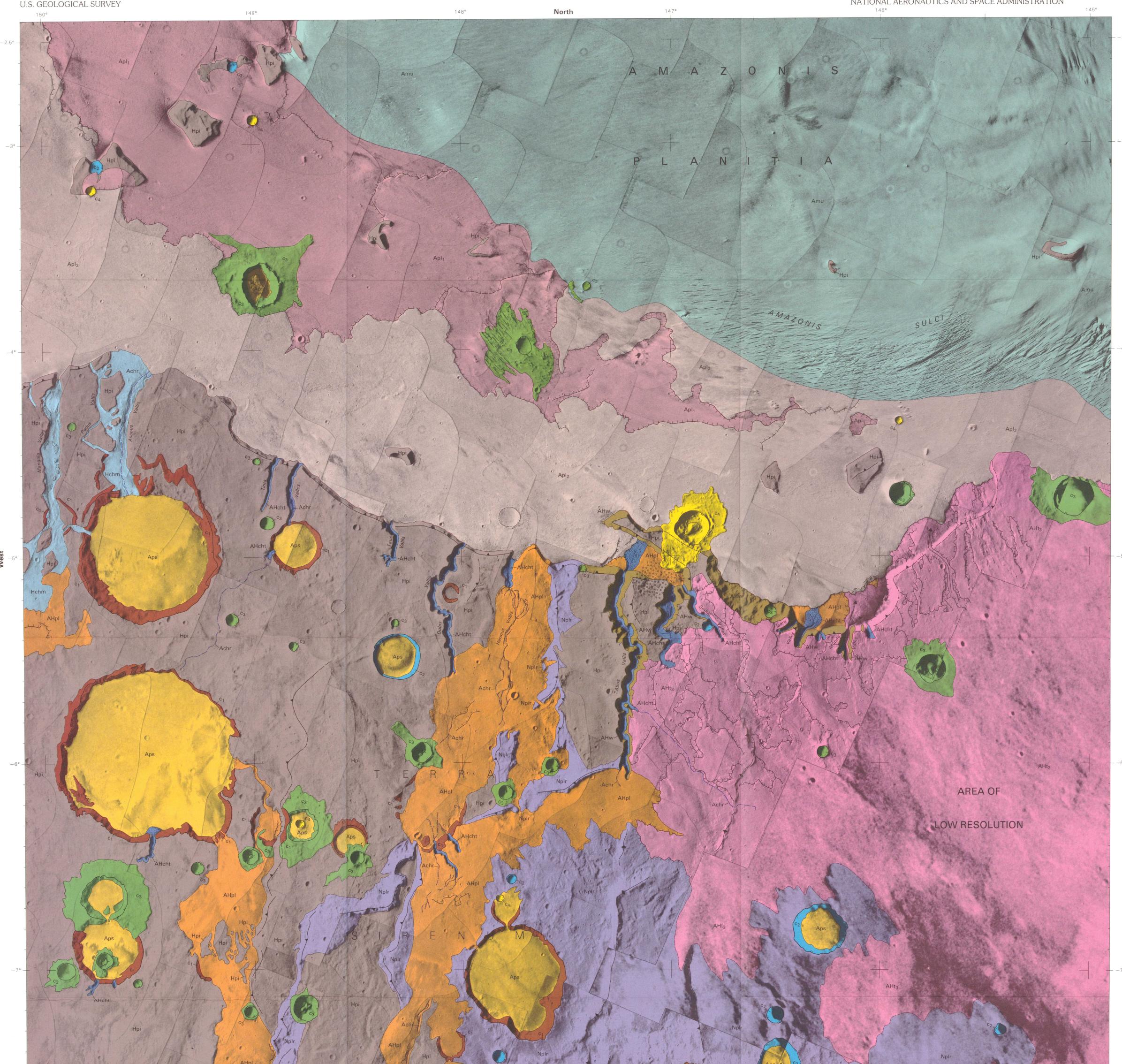
The map area includes two of the easternmost branches of Mangala

small craters are preferentially destroyed.)

function slope of this unit falls off for crater diameters less than 40 km as

mission to Mars.

This map is one in a series of 1:500,000-scale geologic maps initiated



Hchm Material of Mangala Valles branches—Deposits within Asopus and Padus Valles and side branch of broad Mangala Valles channel. Branch channels are broad (3 to 6 km wide), shallow (200 to 300 m deep), and relatively flat floored. Channels contain streamlined elliptical mounds 1 to 3 km long, as wide as 250 m, and as high as 30 m. Interpretation: Fluvial deposits formed during catastrophic flooding that carved Mangala channel. Elliptical mounds are fluvial bars

Prepared on behalf of the Planetary Geology Program, Solar System

Exploration Division, Office of Space Science, National Aeronautics and

Space Administration, under contract W-15,814.

[All mapped craters in area are interpreted to be of impact origin. To avoid uneven portrayal of detail, craters less than 3 km in diameter were not mapped. Craters were assigned to four classes based on state of crater preservation and stratigraphic control. Subscripts refer to degradation

CRATER MATERIALS

sequence from c_1 (most degraded) to c_4 (least degraded)] Material of well-preserved craters—Large crater is bowl shaped, has sharp, complete rim crest, central peak, steep walls, and deep rough floor; ejecta are extensive, are well preserved, and commonly terminate in lobes. Unit superposed on young lobate plains material and older units. Secondary craters form pitted terrain. *Interpretation:* Youngest craters in map area; lobate terminations formed by fluidization of ejecta Material of slightly degraded craters—Rim crests high, complete; craters may have central peaks; walls relatively steep; floors may be rough or partly covered by smooth fill, some are lower than adjacent terrain; extensive ejecta superposed on Hesperian and Noachian units; some crater material partly covered by Amazonian units. Interpretation:

Moderately young crater material

Material of moderately degraded craters—Rim crests low, rounded; some incomplete. Floors generally flat; may be partly filled with sparsely cratered younger material. Sparse ejecta superposed on Hesperian intercrater plains and Noachian material. Interpretation: Moderately old crater material Material of highly degraded craters—Rim crests degraded and low, incomplete, or nearly absent; no central peaks; shallow, flat floors

commonly filled with younger material. Rugged rim crests, in places dissected by channels. Craters occur on Noachian terrain; some are surrounded and partly covered by Hesperian intercrater plains material. No recognizable ejecta. Interpretation: Oldest crater material; of Noachian or possibly Early Hesperian age ———— Contact—Dashed where approximately located

Linear scarp—Line marks top of scarp; barb points downslope; dashed where approximately located **Lobate scarp**—Interpreted as volcanic flow front. Ticks in flow direction;

dashed where approximately located — — Ridge—Dashed where approximately located

Crater rim crest—Dotted where buried Crater central peak

Leveed lava channel—Arrow points in direction of flow Streamlined ridges—Interpreted as yardangs; schematic Fluvial bar and fan deposits

Picondary impact-crater ejecta

and resembles an interdistributary channel on a fan or delta. Because lava flows are not observed at the head of this channel, there is no apparent association with a volcanic unit. The other possible fluvial channel cuts member 3 of the Tharsis Montes Formation, enters Abus Vallis at lat 5.75° S., long 147.1°, and at its terminus cuts material at the mouth of Abus, where traces of earlier abandoned narrow channels are observed at lat 5.0° S., long 147.2° (fig. 2C). Many of these channels may be formed by lava. They display characteristics more commonly associated with lava channels than fluvial ones: they lack tributaries and are locally intermittent, some are associated with lobate scarps or flow fronts, and one ribbon channel of Hermus Vallis appears to contain polygonal interchannel blocks. A ribbon channel that cuts Tinia Valles is the only one that narrows upstream; others maintain constant widths, alternately narrow and widen, or widen upstream. The origin of most of these individual narrow channels cannot be ascertained because some display enigmatic features near the limit of resolution. For example, the interchannel blocks noted above are 2 to 3 pixels wide at 37-m/pixel resolution and appear to be polygonal, but the occurrence of streamlined forms cannot be resolved for such small features. Observed characteristics of these valleys that are common to both fluvial and lava channels include relatively straight courses having only minor undulations and local bifurcation into several branches that rejoin downslope. Multiple mechanisms, including both lava and water erosion, may have formed the channels. Tensional fracturing (Schumm, 1974) may have contributed to their formation, because all exhibit pervasive northward trends. In the previous discussion, the ribbon channels and theater-headed channels were considered to be formed by processes that were nonconcurrent in time. Schumm and Phillips (1986) have compared theater-headed channels in the east Mangala Valles area with similar channels in New Zealand. These authors indicated that although surface flow initially cut the terrestrial channels and small channels continue to remove sediment, the theater-headed terminations and considerable channel widening due to ground-water sapping "leave a false impression" of the significance of the two processes [sapping vs. overland flow] in channel formation." If all of the narrow ribbon channels are fluvial in origin, these channels and the theater-headed channels could represent two morphologic end members of a continuous process. Additional data

The three morphologically different types of small channels in the map area appear to have formed during three separate episodes of channel erosion. Asopus and Padus are broad outwash-channel branches formed by catastrophic flooding in Late Hesperian time. Theater-headed channels appear to have formed in Late Hesperian to Early Amazonian time by sapping or perhaps by composite processes of sapping and overland flow. Finally, the origin of the Lower Amazonian ribbon channels cannot be unequivocally ascertained, but characteristics of at least two channels indicate formation by fluvial systems; others display characteristics common to lava channels. STRUCTURE

The most distinctive scarp in the map area is the east-trending

from future Mars missions are required to resolve this question, which is

important in understanding hydrologic processes once active in this

region of Mars.

highland-lowland boundary scarp, which cuts member 3 of the Tharsis Montes Formation of Hesperian and Amazonian age and all older plains units. However, younger flows of member 3 extend across the scarp at lat 5.4° S., long 146.1° and at lat 5° S., long 145.7°, and the scarp is cut in several places by side branches of Mangala Valles and theater-headed channels. These crosscutting relations suggest that the scarp formed during Late Hesperian time. On photoclinometric profiles of the scarp, measured slopes range from 8° to 25° and heights range from 70 m to 2 km. Steeper slopes and greater heights are associated with greater depths of channel erosion. The origin of the highland-lowland scarp is unknown. Its formation has been attributed to erosion (Scott, 1978; Tanaka, 1986) or to a giant impact (Wilhelms and Squires, 1984), but no definitive features to indicate its origin are observed within the map area. may be interrelated; both may have occurred at the same time in the Late Hesperian. This type of event was modeled in a runoff flume that utilized tilting of the surface and accompanying mist-fall erosion to simulate precipitation and base-level drop along a fault (Phillips, 1988). North-trending scarps cut Hesperian intercrater plains material and Noachian material on Terra Sirenum; ridges on Sirenum also follow this northward trend. South of the map area, these features are truncated by faults of Memnonia Fossae. Old lobate plains material does not contain ridges and is not cut by the scarps (although channel locations appear to be controlled by the northward trends of these features); therefore the

The roughly east trending Memnonia Fossae, which occur south of the map area, cut Hesperian intercrater plains and Noachian ridged plateau materials. Furthermore, water that eroded Mangala Valles and related channels and lava that formed the old lobate plains both appear to have emanated from Memnonia Fossae. We interpret the fossae to be grabens; faults may have provided pathways for water and lava flows. The Memnonia grabens may have resulted from stresses associated with the construction of the Tharsis rise (Wise and others, 1979; Banerdt and others, 1982; Solomon and Head, 1982). Our interpretation agrees with earlier ones that activity on Memnonia Fossae faults occurred in the Early Hesperian and was locally reactivated during the Late Hesperian and Early Amazonian (Plescia and Saunders, 1982; Tanaka, 1986). GEOLOGIC HISTORY

scarps must have formed before the Late Hesperian. On the basis of their

parallel, pervasive trends, we interpret the scarps and ridges to be

The earliest recognizable event in the east Mangala Valles area was partial erosion of the ancient Noachian crust by fluvial activity. The crust was then covered by Hesperian intercrater plains material that probably consists of reworked debris and intercalated volcanic deposits. A period of north-trending faulting then occurred, followed by the formation of roughly east trending Memnonia Fossae to the south. The fossae were the source of catastrophic floods that formed Mangala Valles and of later lava flows (unit AHpI); the location of channels and the direction of lava flows were controlled by the earlier north-trending faults. Theaterheaded channels produced by sapping or possibly by composite processes may have formed concurrently with the highland-lowland boundary scarp that separates Amazonis Planitia from Terra Sirenum. The Tharsis Montes lavas flowed northward to northwestward across Terra Sirenum, covering parts of the theater-headed channels and the boundary scarp. Narrow ribbon channels incised the floors of earlier channels and cut the Tharsis Montes Formation to the south beyond the older channel heads. Amazonis Planitia was then surfaced by Amazonian volcanic units consisting of (1) basalts that locally embayed the boundary scarp, covering channels and older deposits, and (2) a postulated very young ignimbrite deposit in the northeastern part of the map area.

REFERENCES CITED Baker, V.R., and Milton, D.J., 1974, Erosion by catastrophic floods on Mars and Earth: Icarus, v. 23, p. 27-41. Baker, V.R., and Partridge, J.B., 1986, Small Martian valleys: Pristine and degraded morphology: Journal of Geophysical Research, v. 91, no. B3, p. 3561-3572.

Banerdt, W.B., Phillips, R.J., Sleep, N.H., and Saunders, R.S., 1982, Thick shell tectonics on one-plate planets: Application to Mars: Journal of Geophysical Research, v. 87, no. B12, p. 9723-9733. Carr, M.H., and Clow, G.D., 1981, Martian channels and valleys: Their characteristics, distribution, and age: Icarus, v. 48, p. 91-117. Condit, C.D., and Chavez, P.J., Jr., 1979, Basic concepts of computerized digital image processing for geologists: U.S. Geological Survey Bulletin 1462, 16 p. Davis, P.A., and Soderblom, L.A., 1984, Modeling crater topography and albedo from monoscopic Viking Orbiter images, 1. Methodology: Journal of Geophysical Research, v. 89, no. B11, p. 9449-9457. Greeley, Ronald, and Spudis, P.D., 1981, Volcanism on Mars: Reviews

of Geophysics and Space Physics, v. 19, p. 13-41. Kochel, R.C., and Piper, J.F., 1986, Morphology of large valleys on Hawaii: Evidence for groundwater sapping and comparison with Martian valleys: Lunar and Planetary Science Conference, 17th, Proceedings, Part 1, Journal of Geophysical Research, v. 91, no. B13, p. E175-E192. Laity, J.E., 1983, Control on groundwater sapping and valley formation, Colorado Plateau: Physical Geography, v. 4, p. 103-125.

Laity, J.E., and Malin, M.C., 1985, Sapping processes and the development of theater-headed valley networks on the Colorado Plateau: Geological Society of America Bulletin, v. 96, p. 203–217. Masursky, Harold, Boyce, J.M., Dial, A.L., Jr., Schaber, G.G., and Strobell, M.E., 1977, Classification and time of formation of Research, v. 82, no. 28, p. 4016-4038. Milton, D.J., 1973, Water and processes of degradation in the Martian landscape: Journal of Geophysical Research, v. 78, no. 20, p.

Mutch, T.A., and Morris, E.C., 1979, Geologic map of the Memnonia quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I-1137, scale 1:5,000,000. Phillips, Loren, 1988, The effect of slope on experimental drainage patterns: Possible application on Mars, in Sapping features on the Colorado Plateau: A comparative planetary geology field guide: National Aeronautics and Space Administration Special Publication 491, p. 107. Pieri, D.C., 1980, Geomorphology of Martian valleys, in Woronow, Alex,

ed., Advances in planetary geology: National Aeronautics and Space Administration Technical Memorandum 81979, p. 1–160. Plescia, J.B., and Saunders, R.S., 1982, Tectonic history of the Tharsis region, Mars: Journal of Geophysical Research, v. 87, no. B12, p. 9775-9791 Schultz, P.H., 1985, Polar wanderings on Mars: Scientific American, v. 253, no. 6, p. 94-102. Schultz, P.H., and Lutz, A.B., 1988, Polar wandering of Mars: Icarus, v. 73, p. 91-141.

Schumm, S.A., 1974, Structural origin of large Martian channels: Icarus,

v. 22, p. 371–384. Schumm, S.A., and Phillips, Loren, 1986, Composite channels of the Canterbury Plain, New Zealand: A Martian analog?: Geology, v. 14. p. 326–329. Scott, D.H., 1978, Mars, highlands-lowlands: Viking contributions to Mariner relative age studies: Icarus, v. 34, p. 479-485. Scott, D.H., and Carr, M.H., 1978, Geologic map of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I-1083, scale 1:25,000,000. Scott, D.H., and Schaber, G.G., 1981, Map showing lava flows in the

scale 1:2.000.000. Scott, D.H., and Tanaka, K.L., 1982, Ignimbrites of the Amazonis Planitia region of Mars: Journal of Geophysical Research, v. 87, no. B12, p. 1179-1190. __ 1986, Geologic map of the western equatorial region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I-1802-A, scale 1:15,000,000. Sharp, R.P., and Malin, M.C., 1975, Channels on Mars: Geological Society of America Bulletin, v. 86, p. 593-609.

Solomon, S.C., and Head, J.W., 1982, Evolution of the Tharsis province

northeast part of the Memnonia quadrangle of Mars: U.S. Geo-

logical Survey Miscellaneous Investigations Series Map I-1270,

of Mars: The importance of heterogeneous lithospheric thickness and volcanic construction: Journal of Geophysical Research, v. 87, no. B12, p. 9755-9774. Tanaka, K.L., 1986, The stratigraphy of Mars: Lunar and Planetary Science Conference, 17th, Proceedings, Part 1, Journal of Geophysical Research, v. 91, no. B13, p. E139-E158. U.S. Geological Survey, 1985, Controlled photomosaic of part of the Mangala Valles region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I-1664, scale 1:500,000. Walker, G.P.L., 1972, Compound and simple lava flows and flood basalts: Bulletin of Volcanology, v. 35, p. 579-590. Ward, A.W., 1979, Yardangs on Mars: Evidence of recent wind erosion: Journal of Geophysical Research, v. 84, no. B14, p. 8147-8166. Wilhelms, D.E., and Squires, S.W., 1984, The martian hemispheric

dichotomy may be due to a giant impact: Nature, v. 309, p.

1985; Kochel and Piper, 1986). Wise, D.U., Golombek, M.P., and McGill, G.E., 1979, Tharsis province CHANNEL TYPE 3: RIBBON CHANNELS of Mars: Geologic sequence, geometry, and a deformation mechanism: Icarus, v. 38, p. 456-472. Elongate deposits (unit Achr) occur in narrow ribbon channels, which cut the older channel-floor material of Asopus, Tinia (fig. 2B), Hermus, Abus (figs. 2C, 3), Senus, Isara, and Munda Valles as well as member 3 of the Tharsis Montes Formation. They predate the young lobate plains unit: a lava tongue of this plains material fills the mouth of

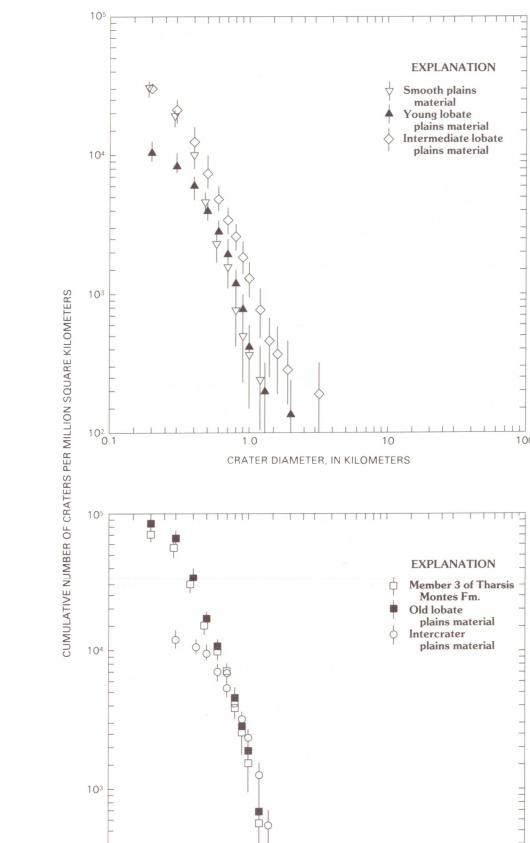
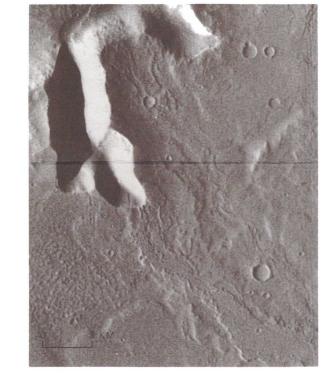
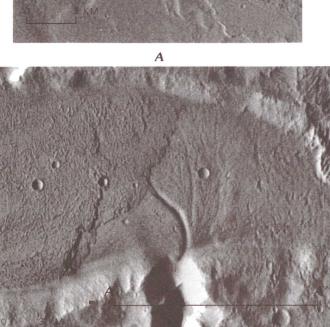


Figure 1.—Log-log cumulative crater size-frequency curves for principal geologic units in map area. Bars represent standard error (\sqrt{N}/A , where N = cumulative number of craters and A = unit area).

CRATER DIAMETER, IN KILOMETERS





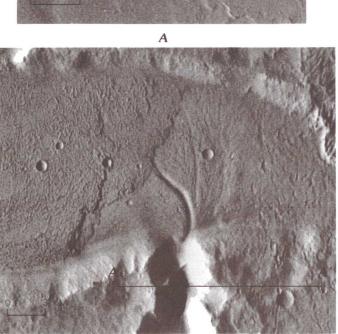
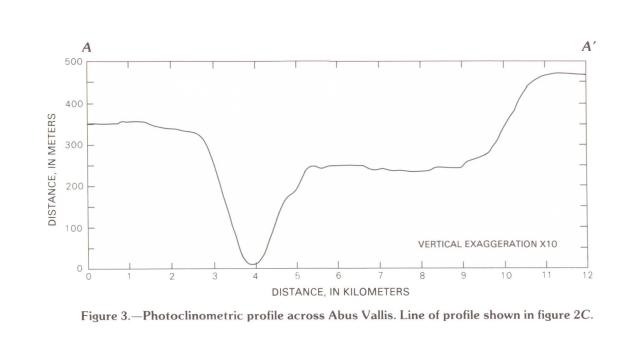
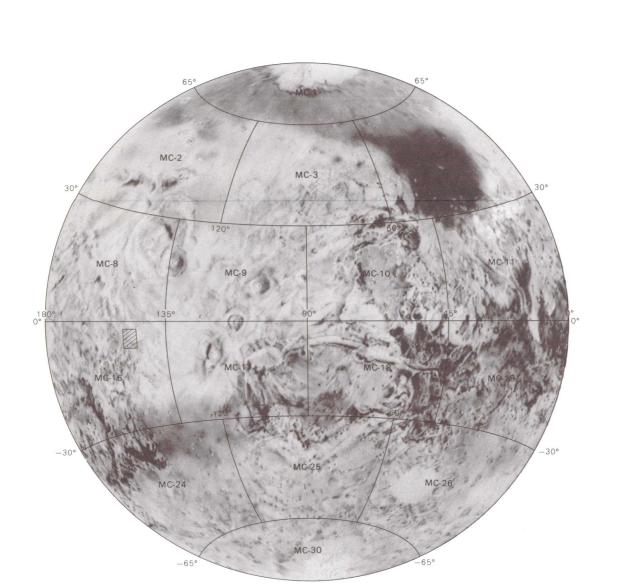


Figure 2.—Images showing relations of channels and lithologic units in map area. North at top; scale bars = 3 km. A, Basaltic flows of member 3 of the Tharsis Montes Formation covering head of Munda Vallis, a theater-headed channel. B, Narrow ribbon channel cut into wider theater-headed channel (east channel of Tinia Valles). C, Abus Vallis, a theater-headed channel, and inner ribbon channel, to left of older narrow incisions; young lobate plains unit covers north end of ribbon channel. Line A-A' indicates position of profile shown in figure 3. D, Hermus Vallis, a theater-headed channel, incised by younger, narrow ribbon channel; basaltic young lobate plains unit embays channel mouth.





QUADRANGLE LOCATION Photomosaic location is shown in the western hemisphere of Mars. An outline of 1:5,000,000-scale quadrangles is provided

is based on the 1978 control net (Davies and others, 1978), the 1982 control net (Davies and Katayama, 1983), and the Mars control network (Wu and Schafer, 1984). These nets contain published standard errors of approximately 5 km, and agreement of points common to the nets may differ by as much as 1 cm at map scale. Image points from 1:2,000,000-scale controlled photomosaics were transferred to the Transverse Mercator projection where control points are sparse or not available. The density, distribution, precision, and accuracy of available INDEX OF VIKING PICTURES

control points used for this map series are extremely variable. A block of mosaics compiled in areas of optimum control-point distribution is not likely to match adjacent blocks previously compiled in areas of sparse or imprecise control. Where discrepancies exist between adjacent mosaics, the more recent compilation is probably more accurate. No attempt was made to resolve large edge discrepancies with previous compilations. The projection is based on a Mars Transverse Mercator (MTM) system with 20° zones. The scale factor at the central meridian of the zone containing this quadrangle is 0.9960. The projection scale is based on an oblate spheroid (flattening of 1/192) with an equatorial radius of 3393.4 km and a polar radius of 3375.7 km. NOMENCLATURE. All names shown on the reduced base mosaic are approved by the International Astronomical Union (IAU, 1974, 1980, 1986). MTM -05147 Abbreviation for Mars; Transverse Mercator projection: sheet -05147 M 500K -5/147 CM Abbreviation for Mars; 1:500,000

series; center of sheet lat 5° S., long 147°; controlled photomosaic (CM) REFERENCES Davies, M.E., and Katayama, F.Y., 1983, The 1982 control network of Mars: Journal of Geophysical Research, v. 88, no. B9, p. 7503-7504. Davies, M.E., Katayama, F.Y., and Roth, J.A., 1978, Control net of Mars: February 1978: The Rand Corporation, R-2309-NASA, 91 p. International Astronomical Union, 1974, Commission 16: Physical study of planets and satellites, and Lunar and martian nomenclature, in 15th General Assembly, Sydney, 1973,

NOTES ON BASE

show areas of special interest on Mars. Viking Orbiter high-

resolution pictures (less than 100 m per picture element) were

used to make the mosaic. The images have been digitally

enhanced to accentuate high-frequency detail. Image placement

This photomosaic is part of a series of quadrangles selected to

DEPARTMENT OF THE INTERIOR

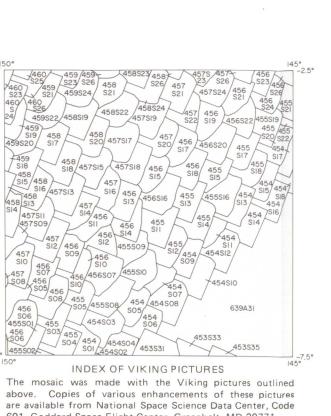
Proceedings: International Astronomical Union Transac tions, v. 15B, p. 105-108, 217-221. _____ 1980, Working Group for Planetary System Nomenclature, in 17th General Assembly, Montreal, 1979. Proceedings: International Astronomical Union Transactions, v. 17B, p. 293-297. _____ 1986, Working Group for Planetary System Nomenclature, in 19th General Assembly, New Delhi, 1985, Proceedings: International Astronomical Union Transactions, v. 19B, p. 347–350. Wu, S.S.C., and Schafer, F.J., 1984, Mars control network:

American Society of Photogrammetry, in Technical papers

of the 50th annual meeting of the American Society of

1984, p. 456-463.

Photogrammetry, v. 2, Washington, D.C., March 11-16,



601, Goddard Space Flight Center, Greenbelt, MD 20771.

PLAINS WALL CHANNEL-FLOOR CRATER MATERIALS MATERIAL MATERIALS MATERIALS Amazonian Middle Lower Noachian *Series boundaries from Tanka (1986)

CORRELATION OF MAP UNITS

DESCRIPTION OF MAP UNITS PLAINS MATERIALS

SCALE 1:502 000 (1 mm = 502 m) AT 150° LONGITUDE

TRANSVERSE MERCATOR PROJECTION

10 0 10 20 30 40 50 60 70 80 90 100

KILOMETERS

Lobate scarps on material units are interpreted to be lava flow fronts] Upper member of the Medusae Fossae Formation—In northeastern part of map area; forms nearly featureless, massive blanket without visible bedding. Relatively high but varied albedo. Northeast-trending subparallel streamlined ridges (1 to 4 km long) occur locally along south margin. Interpretation: Pyroclastic flows whose distal and upper zones are poorly lithified; ridges are yardangs. Age based on stratigraphic position; crater counts on nonindurated material are indeterminate due to eolian modification

Smooth plains material—Smooth deposits within most large (10- to 50-km diameter) craters on Terra Sirenum. Crater density 340 ± 90. Interpretation: Smooth surfaces and occurrence in topographic depressions suggest eolian origin; age determined by crater density Young lobate plains material—Forms east-trending belt along south border of Amazonis Planitia. Surface relatively smooth; many fine, sublinear ridges and depressions with as much as 10 m of relief. Bounded by low (30 m high) lobate and crenulate scarp. Crater density 440 ± 160 . Interpretation: Youngest basaltic lava flow in map area. Fine sublinear features are pressure ridges and cooling cracks

Apl₁ Intermediate lobate plains material—Forms broad, relatively smooth plains in Amazonia Planitia; low albedo. Locally contains sparse, low, lobate scarps and fine, sublinear ridges and depressions. Crater density $1,300 \pm 350$. Interpretation: Basaltic lava flows. Ridges and depressions may be pressure ridges and cooling cracks

Member 3 of the Tharsis Montes Formation—In southeast quarter of map area, seen as numerous overlapping tongues bounded by irregularly digitate, low, stepped, lobate scarps, rising southeastward toward Tharsis Montes. Leveed lava channels overlie highland-lowland scarp and theater-headed channel. Crater density 1,800 \pm 700. *Interpretation*: Basaltic lavas associated with Tharsis volcanism; northwest flow followed basaltic volcanism

regional slope of Terra Sirenum. Leveed lava channels also suggest Old lobate plains material—Moderately smooth surfaces; occurs within north-trending depressions. Bounded by and contains sparse, low-relief, lobate scarps, which rise southward in successive steps. Unit traceable in low-resolution images to Memnonia Fossae. Crater density $1,900 \pm 900$. Interpretation: North-flowing basaltic lavas extruded from vents associated with Memnonia Fossae Intercrater plains material—In southwestern part of map area; forms moderately rough surfaces partly broken by north-trending fractures;

albedo high. Abuts ridged plateau material and c1 crater rims. Local mesas and buttes in Amazonis Planitia. Small, degraded channels underlie unit southwest of map area at lat 7° S., long 158.2°. Density of small, degraded craters 2,400 \pm 300. *Interpretation*: Intercalated basaltic flows and volcaniclastic deposits; mantles ridged plateau unit Ridged plateau material—Occurs as isolated blocks of rough, heavily fractured and cratered material containing ridges; protrudes through younger intercrater plains material on Terra Sirenum. Lacks diagnostic geomorphic features indicative of lithology. Crater density 40 (at 40-km diameter) per 106 km². Interpretation: Early Martian crust; geomorphic features erased by heavy impact bombardment and erosion by masswasting, eolian, and fluvial processes

WALL MATERIAL Wall material, undivided—Smooth material on steep scarps and walls of canyons. Poor discrimination due to illumination-related shadows and glare. Interpretation: Aprons probably consisting of sequences of lava flows, crater ejecta, and fluvial and eolian materials CHANNEL-FLOOR MATERIALS

[All channels trend north and lack tributaries. Most occur on Terra Sirenum] Material of ribbon channels—Elongate deposits (20 to 70 km long) within narrow (300 to 800 m wide), shallow (20 to 60 m deep) channels incised into low areas of Terra Sirenum or older channel-floor materials; some extend onto Amazonis Planitia. Channels relatively straight and in places bifurcate and rejoin; indistinct sources; some channels may head in old lobate plains material and Tharsis Montes Formation. Interpretation: Youngest channel deposits. Genesis of narrow channels uncertain; two channels appear fluvial in origin, others are possible lava channels Material of theater-headed channels—Smooth, relatively elongate

deposits. Channels cut highland-lowland boundary scarp and c1 crater rims, and material forms lobes at some channel mouths. Channels are 1 to 3 km wide, deeply incised (100 to 1,500 m deep), and 6 to 60 km long; originate at theater heads. Interpretation: Young fluvial deposits; water derived from ground-water sapping. Lobes are fan deposits formed by

eolian and fluvial processes

GEOLOGIC MAP

GEOLOGIC MAPS OF SCIENCE STUDY SITE 1A, EAST MANGALA VALLES, MARS